**Giant Planets Meeting: October 26, 2009**

**Open Session**

**Sushil Atreya presentation on giant planet probes**

- Galileo probe entered a dry spot
    - Performed very well – twice the expectation
    - Went to about 22 bars
- Measurements of heavy elements are very important to understanding Jupiter formation
- Don't yet know about water
    - Juno will help with this for Jupiter
    - But nothing yet for Saturn
- Comparison between Jupiter and Saturn is very important – did they form the same way?
- Saturn probe was dropped from Cassini mission, just left with Titan probe but was originally planned
- Cassini has measured carbon and phosphine to get P abundance

- Technical problems with deep probe – communications and survival of instruments in high pressure and temp (100 bar and 550 K)
- Also issues with maintaining power to the probes
- But don't need a deep probe if we don't need to measure water, shallow probes are adequate for all heavy elements except oxygen
- 2-3 probes recommended for Saturn diversity and risk mitigation
- Probe mission was studied by TeamX for New Frontiers
    - Cost was above cost cap ~900 million
- Asks the committee to consider a shallow Saturn dual probe mission with microwave radiometry from carrier spacecraft
- Prefers an orbiter to map water and other volatiles, determine if there is a core and how big
- Consider a new line of small Flagship class missions 1.2-1.5 billion as a program
    - Will serve outer planet community well for systematic and sustained exploration of all giant planets
- ? Cost of last study?
    - ~900 million for flyby with microwave and two probes costed at JPL
    - Other people suggest that it could be done under NF
- ? Science case could be addressed by mass spec on probe. What should instruments be?
    - Did not want to list them, but mass spec was 1980s tech on Galileo, not enough precision
    - Tunable laser spec used with mass spec would be tremendous

    - Nephelometry
        - Measurements of pressure and temp
- ? Statement that Cassini will not measure isotopes or heavy elements, but with current plan for end of mission design (skimming atmosphere for several orbits) hopefully - for things like noble gases are they well enough mixed to high altitudes to measure them?
    - Possibly well-mixed to below homopause ~800 km
    - Cannot access all noble gases even at that level by INMS instrument– some not covered in range of instrument (Ne and He and isotopes)
    - Isotopes very small in abundance, need diff type of instrument
    - Could get Kr, Xe
- ? Proposing mini flagship still sounds like a hard sell because it does not have the same large scope as Cassini. Is there a way to scale down probes (only 1 or not MWR or orbiter)? What's the cheapest?
    - If dumb it down to not get oxygen measurements, but still noble gases and single probe, remove microwave
        - Could do it within NF, but needs more study
- ? Is orbiter required for microwave radiometer?
    - No – could do a few measurement of water vapor from flyby
    - But does not get a map of water vapor
- ? For exoplanets – which measurement of what planet is more important?
    - Would go after Saturn first to get a full picture and also for comparison with Jupiter
- ? On probe – did you call for a redundant He/H measurement like Galileo?
    - Not really essential, but wouldn't be expensive to include He detector
- ? Tactical – to get this in next 20 years, should recommend "skinny" probe to put emphasis on tech development?
    - Can do this now with current tech
    - ? Need RTGs?
        - JPL used solar panels

**Probes Technology – Tony Colaprete**

- Key science objectives for Saturn are really to understand composition and most important elemental ratios
- Probes are hugely complementary to Cassini mission
- ? Fundamental problem – how deep is the water?
    - Anything below 30 bars should strongly constrain current models of interior convection
- Environmental constraint – tech exists for entry system, high T and P measurement systems are ready
- Most mission studies use "Galileo-stock" probes
    - But can't get very deep and get to high cost quickly

- Arguing for not doing Galileo heritage probes if want to go deeper
    - Atmosphere structure measurement and neutral mass spec instruments (or GCMS) are the only really necessary ones
    - This more than halves the data, mass, and power of the payload
    - 100 kg probe is very achievable
- Additional instruments could be
    - Tunable diode laser
    - Microwave radiometer – but is better on orbiter than flyby
- Must overcome atmosphere attenuation and slow descent time to get a deep probe
- New Alternate Architecture
    - How do you get deep? Either you don't and instead use microwave radiometry
        - Or extend relay concept to a "chain of probes"
        - Mother probe stays shallow with chute to slow descent (my question – what would you make the parachute out of ?)
        - Probelet (dropsonde) dropped for free descent with full payload compliment
        - Maintains comlink
    - Asking for a fresh look at the trade space
- ? This is new tech, no heritage?
    - Architecture has never been done, but hardware is not necessarily new
- ? Dropping probes from orbit?
    - No, swingby to drop probes with single aeroshell
    - To go into orbit brings you to Flagship class
    - Will give you enough time to get data, but problem is getting the probe to drop fast enough so the flyby spacecraft doesn't go out of view – need smaller data rate and volume
- ? Congrats on new idea – specific giant planet probe mission
    - Crosscutting application for Venus at 30-40 bars
- ? Key is don't have to carry power supply to deepest level?
    - Yes, small payload means fewer batteries on dropsonde – emphasis on antennae to communicate with mother probe
    - Also is protected by pressure vessel of mother probe going in
- Comment – is very innovative idea to stage the probes, but skeptical of power and mass assumptions going down so low

**Michael Wong: Time Domain Science by Planetary Space Telescope**

- Requirements are sampling interval and campaign duration
- Ground-based telescopes are shared by many users so difficult to get enough time to conduct study
- Mission – Planetary Dynamics Explorer (PDX)

    - Science goals overarching for many planetary bodies
    - Helps to understand how the solar system is constantly changing
- Comparing this advance to the change from still photos to motion pictures and the creation of weather satellites
- Close coincidence between planetary and other astronomers is widening, facilities are just not set up for desired planetary measurements
- Lots of support in other white papers – Saturn, Ganymede, Io, Uranus and Neptune, Jupiter
    - All these are looking for seasonal changes over many years
- Lots of atmospheric studies including occultations
- Volcanic activity
- Aurorae and magnetospheres
- Cometary evolution, etc
- Example science – Jupiter's haze belt
    - Looked at Hubble's record over years, but have big data gaps
- Also Jupiter vortex dynamics – e.g. oval BA turned red
- Technology – distributed or sparse aperture can reduce the volume of payload, not requiring a high sensitivity for these observations
    - Can have same angular resolution
    - Other cost considerations
        - Instrumentation – IR Integral Field Spectrometer, Visible camera, UV spectrometer at least
        - Orbit – HEO, Moon libration points, or Earth-Sun libration points
            - At least HEO to avoid diurnal interruptions
        - Attitude control – need frequent changes
        - Could use observation template to streamline scheduling
        - If put at libration points, could be a target for manned space program if using "flexible path"
        - Also could be a model for optical communication system
    - Would maintain UV and optical capabilities past Hubble
    - "'Current state' of the solar system is a myth!"
- ? The stable suborbital platforms would not be good enough?
    - Could use them for occultations but some observations require longer campaign lengths
- ? Has the distributed aperture technology been proven?
    - Has been proven on ground, but no yet in space
- ? Can't have years on suborbital, but could relaunch it for cheaper. How do you balance that?
    - Not sure about payload for balloons, may not get angular resolutions needed

**Dave Content – Technologies for Space Telescopes**

- Don't see this as a deep cryogenic observatory like JWST. Would not need to deploy it
- Discussing the tech requirements for Wong et al white paper concept
- ITT corrugated glass mirror at TRL 5 right now – is a way to make it less expensive
- Some good tech options, but most (all?) require more development
- GAIA currently in development – large segmented structures in SiC
  - Could build this for cryogenics
- Can make phasing steps shorter than JWST since is mature tech now and fewer segments and smaller
- Could build this as a monolithic telescope for 3-4 m
  - Not obvious which is easier because still have to phase the multiples
- Likely to conclude that want somewhat cooled to get to middle IR, but not nearly so cool as JWST, but will be more expensive than room temp
- Hard parts are matching and phasing subapertures but can test all this on the ground – just have to build prototype early
- Trade between many different types of segments versus performance
- Goddard has what is needed to study, design, and build this system
- ? How are you defining medium cost?
  - Avoid this becoming a facility – type cost.
  - ? Order of magnitude
    - Less costly than JDEM because it has a smaller field of view
    - ~ 1 billion as a guess. Doing anything to GEO is expensive
- ? What would happen if wasn't at GEO, but was in LEO?
  - Couldn't get consistent observations?
  - ? What's the trade space?
    - Really gets back to launch vehicles
- ? Understanding phasing of sparse apertures – identical between segmented mirrors or discrete telescopes?
  - Easier with discrete telescopes
  - ? Not much flight heritage because can't be discussed?
    - Not going to be call for this broad a band in other applications
- ? What if restricted to UV and optical?
  - Cost would be less because it no longer needs to be cold, could use closer to heritage tech or direct heritage
- ? Keep in mind that astrophysics missions are trying to go faint in near IR

**Beverly Cook – Deep Space Network**

See the webcast of the presentation

**Radioisotope Power Systems**

- We're out – no longer have the right chemical processing facilities (no one does)

- Have purchased all the 238Pu that the Russians have
- Yes, we need RPS to do missions
- Can we use something else? No.
- DOE runs the facilities and is the only agency that can do so. NASA can get the money, but would have to give it to the DOE to build, operate, and regulate
- Already making mission-limiting decisions
- **MSL, one scout mission, and Flagship 1**
  - **After that, no more**
- If facility gets into 2010 budget, takes 7 years to make Pu, best case is still out of Pu for a period of time given current demand
- Right now, we have a shortfall in those years 2024-2028
- Budget was killed – said that should resubmit, but should figure out how to charge NASA for it (to build chemical processing facility)
  - But NASA can't own nuclear processing facilities legally
- ? AAS is going to be lobbying Congress directly
- Even if money is given to NASA to give to DOE, it's still problematic because NASA would have to do their own environmental impact study
- Need to have yearly letters from NASA to say what they need
- If have facility, can make 5 kg per year
- Would be good to have multi-mission RTGs
- ?MMRTGs – NASA or DOE?
  - NASA pays for hardware but not for infrastructure
- ASRG flight readiness timetable needed, but budget is really small so can't afford to test the full system
- NASA needs a technology plan with prioritized goals, techs, lists of facilities and skills
- ASRGs would really help to delay the problem
- ? Gap of 8-10 years, is there a way to shorten this?
  - No. Depends on facilities building, radiation time, letting the products sit for a while
- ? International efforts?
  - Still have to build chemical processing facility, but not going to build that in another country
- ? Btw 2018-2023 we just don't have any Pu.
- The entire US government is out. DOD has said they have no demand.
- Language says that need to come together with DoE for cost sharing, but that is what they've been doing

**Pat Beauchamp – OPAG technology priorities**

Follow on to Bill McKinnon's presentation
- Number 1 priority – Pu
- First step in planetary protection is a policy issue
- For entry systems, have things to build on, but new ones are needed
- Good summary of specific OPAG recommendations

- Has to be sustained development program for the Titan balloon
- ? Ka band getting to routine use
    - Yes
    - Used JPL for communications section, coordinated with people working on DSN
    - Infrastructure is down, but need to get spacecraft to use it
        - Ground based end is pretty much ready
- ? Extreme environments – talk about g forces and survivability?
    - Yes – in the paper
- ? It would be nice to see more detail on solar arrays surviving orbit insertion and particular environments
- ? Talking about inflatable arrays – any answer to Pu problem in solar arrays even out at Uranus?
    - We have an RMA addressing this issue
        - End up energy managing very critically – scary risk
        - Works for flyby but very difficult for orbiters
- ? Solar electric propulsion – not seen as a major issue at the moment?
    - No, would like to make sure it continues. Good for risk reduction and getting to target faster
    - New and advanced development for improving capability, but fairly straightforward to fly these
- ? Consider earth orbit or sub orbit based systems at all?
    - No, just looking at outer planet mission sets currently
    - ? Why? – just the interests from the people who want to do them

**Leigh Fletcher EJSM Science goals – 8 themes**

- ? Not going to address the bulk comp of Jupiter or internal structure?
    - Some redundancy if Juno fails
- ? Regarding the 1st 6 goals, since ESA part has not been fully committed, how do we make the NASA part more resilient?
    - Are shared instruments on both orbiters but not full redundancy
    - The assignment to science team was from point of optimism
- ? No goals with rings?
    - Separate small bodies and rings working group, not considered by Jupiter group
- Intention to get fully global Jupiter climate database, visible, nIR, UV
- Could increase spectral ranges of instruments to increase Jupiter science
- Regular, repeated investigations would answer a lot of outstanding questions
- EJSM focus purely on atmosphere, not deep like Juno
    - Even though the payload is satellite-focused
- Aim to allow proposers the scope and depth to address Jupiter science questions
- ? IR imaging resolution not sufficient – does the improvement require redesign, or just small change?

        - Model payload only right now based on heritage instruments
        - ? Current limitations?
            - Need to talk to instrument provider, but spectral range is not quite enough right now
            - Probably comes down to mass and money (and a little bit power)
- ? Clarify during early Jupiter orbits, how many days or weeks will be superior to ground-based?
    - nIR and visible vastly superior
    - ~2 weeks with high spatial resolution
    - Standard nIR 300-400 km resolution at most
- ? Mostly equatorial?
    - Yes

**Krishan Khurana and Fran Bagenal – Planetary Magnetospheres**

- Comparative magnetospheres
    - Jupiter's magnetosphere is huge
        - Visited by 7 spacecraft, but poor coverage at high latitude
        - Gets plasma from Io at 1-2 tons/sec
        - Has a huge amount of energy
        - Magnetic field forces the plasma to corotate as it moves outward
        - Plasma extracts ~5x10^13 W of energy from the ionosphere of Jupiter
        - Still questions about reconnection of the magnetosphere
        - Jovian aurorae
            - Can see from Hubble
            - Processes are still poorly understood, but important for determining chemistry and structure of the upper atmosphere
    - Saturn
        - Fast rotator
        - Plasma derived from Enceladus mostly as charged H, O, and OH
        - 100 times as many neutrals as ions – opposite of Jupiter
        - Much cooler than Jupiter's plasma
        - Periodicity of 10 hours
        - SKR intensity period organizes many datasets in Saturn's magnetosphere, but why?
        - Aurorae – also powered by plasma, but innermost edges could also be solar wind electric field
    - Uranus
        - Very large tilt
        - Don't understand the source of the magnetic field

        - Plasma derived mostly from Uranus but may be some captured solar wind
        - To get to the real story, need data from an orbiter, long term for secular variations
        - Shallow dynamo, so likely that orbit for only a few years would show cyclical variation
        - No heavy ions derived from moons (unique among outer planets)
        - Magnetotail is rotating but is delayed with distance and plasma is corotating
        - Very energetic particles, stable trapping environment for both electrons and ions
        - ? Don't care about solstice vs. equinox?
            - Missions would likely be solstice
    - Neptune
        - Lowest particle density but derives plasma from Triton
        - Not symmetric
        - Don't know spin period, need orbiter to determine this
    - Triton
        - Has strong neutral gas torus inferred from plasma observations
- ? Have not imaged aurora from Uranus or Neptune?
    - No, but they are suspected
- Key unanswered questions –
    - See lists in the presentation
- ? Could you match your questions to missions more directly?
    - Yes, will do that
- Learned from Cassini that can do both equatorial and polar orbits
- Recommendations: Near term, support Cassini. Longer term, Jupiter mission to magnetosphere
- ? Error bar on Uranus rotation +- 36 secs, should be bigger?
    - Yes, much bigger
    - Not a good enough measurement to get Uranus's rotation period
- ? Auroral imaging should be higher priority?
    - Yes, it is often only an afterthought

**Tom Spilker – JPL's RMA study of Neptune mission**

- Guiding science questions taken from vision mission studies of Neptune orbiter with probes
- Launch timeframe 2022-2035 depending if NF or flagship
- Assumed ASRGs and MMRTGs available but fission reactors were not
- Main challenges:
    - Long way out there – 30 AU
        - Lots of factors in delivered mass vs mission duration
        - Lifetime limits of equipment

        - Deployments after you get there
        - Programmatic reticence for long duration missions
        - ? Component lifetimes are major factors?
            - Mainly RPS – not tested past 14 years (design specification)
            - Don't know what life-limiting issue is, will eventually get data if we let it run, but can't do accelerated testing
        - ? Bearings might go out or something like that
            - So can only practically use the design lifetime
            - MMRTGs last practically forever, but we can't use that
    - Aerocapture is still a problem
    - Communications difficult – low bandwidth
    - Looked at several different payload options
- 2 year tour gets you most of the observations you want but misses seasonal changes
- Not going to be like Cassini mission – just can't take as much out there
- ? Behind these numbers on science value matrix, there's some formula, right?
    - No, these are put together by the science panel (tan columns on left) and the rest are worked out in the math
- ? Worry about lack of correspondence with science goals
    - Have to make them clear, discrete, and not very numerous. They're mapped but…
    - From JPL – it is a 1:1 mapping, and the intent is to be so!
    - Someone could come up with a better tool, but need a way to relatively order things in importance of science value
- Most important figure – ordering of science value vs total mission cost of different mission possibilities
    - ? Normalized?
        - Normalized to one particular mission (not money) (may be a normal flagship cost) but this mission is 20% more expensive than another...
    - ? Something wrong with science scaling guide – value of adding a probe isn't right
        - Lots are above average, but some cost a whole lot more to be slightly above average
    - Risk box next to spots – flyby has green risk
        - Mission (technical) risk on left
        - Implementation risk on right
    - ? What are you doing to improve science value methodology?
        - Comes down to the science team putting together the priorities
    - Will have scores and relative costs by end of sessions for science teams to look at
    - ? Is the scoring being done among small set in real time, or can everyone absorb it later?

        - No, real time. Must be paying very close attention at the time
- ? Worried about criteria for valuation of science so that we aren't still arguing a year from now.
    - Will work on how to do the priorities as long as we all agree on science goals
- Not going to go all the way down to blueprints, but as an analogy, science can't go all the way down to a fully developed traceability matrix. Lot of it is going to be science intuition of people involved
- ? If amount of electric power was 2-4 times you have now, would that change output?
    - Yes, would increase science values
    - ? Why so quick to dismiss reactor power? 1200 W
        - Don't think it's out of scope for the committee to consider these
- Results – no objectives were make or break. So many different ones that you can do – this is a very good thing
- Particular candidates for further study
    - NF mission – various flavors
    - Simple orbiter in small flagship cost – depends on how much you want to do Triton
    - Multiple flagship missions – combos of high capability orbiter (core of the missions) with possible entry probes, landers, etc.
        - Probes seem very worthwhile
- Worthwhile going to a KBO on a flyby as well – involves a wider community, more science value
- Sour spots – dependent on having Jupiter gravity assist in short windows or have to have Ares V
- Good opportunities for international collaboration where there are clean interfaces
- For follow-on study, what will change?
    - Science goals and objectives and priorities
    - Driving assumptions and constraints
        - Margins, DSN assumptions
        - More emphasis on smaller size – payload and flight elements